Nano Compound Devices

The emergence of phage ‘viruses’ at MIT as the new compound tool kit or November’s launch of the first nano blog to cover thin film, organic and printable electronics (http://blog.nanomarkets.net/blog/client) are just two of the deluge of nano developments all clamouring for the III-V industry’s attention. However, the common thread for success with material, equipment, devices or markets, as defined by Aixtron’s Rainier Beccard, is ‘control in more than one dimension’.

In April this year, the first workshop on Merging Optics and Nanotechnologies (MONA) was held in Strasbourg. Its participants considered nano-scale materials, equipment and processes, applications, and markets. The second workshop/symposium in Grenoble at the end of November will show nanomaterials further shifting boundaries, processes adapted and nano-processing equipment moving into fab and lab, with compounds almost inevitable presence where quantum dots or wells, nano rods, wires or tubes are being developed.

More recent reports from the November SEMI NanoForum in San Jose, indicate that improved control of the phage display process (viruses) to make nanowires has created a totally new toolkit (Figure 1) for an expanding range of new applications, ranging from flagging up silicon dislocation and defects in germanium-on-silicon wafers to assembling alloys for thin film battery anodes. MIT professor, Angela Belcher, is on record as saying that “it typically takes about five rounds to get an organism that attaches stably to the desired metal, insulator or semiconductor. … New genetic engineering in the last year now allows for alloys, although ‘work on InGaN for solar cells’ is proving slightly tricky.

Simultaneously, nanoscale surface engineering is reported as beginning to enable economic low energy white LED lighting. UCSB’s Steve Denbaars showed that nano control of semiconductor deposition, doping and nano-engineering surfaces (allowing 2x to 3x improvements) could produce high efficiency economic LED light in around two years. Progress, he says, has brought the white GaN LED up to 130 lm/W at 20 mA. The LEDs use an indium tin oxide electrode with a 95% transmittance rather than Ni/Al p contact with only 40% transmittance. It follows on from Cree’s achievement of a 131 lm/W at 20 mA in summer.

Asked where he saw compound materials playing their part in nano device developments, Dr Michael Lebby, president and executive director of the Optoelectronics Industry Development Association (OIDA) said that the quick answer was in three major areas: displays, solar and lighting (high-brightness LEDs – HB-LEDs).

He noted that other ‘hot’ sectors currently are quantum dots, nanorods, wires and tubes (Figure 2) and suggested CsSe/CdTe nanocrystal solar cells, and nanocomposite materials (such as inks) for solar cell applications were developing fast. Nanosys, the industry bell-weather, bears out this assessment. This year it won a tranche of complementary patents and pending patents (No: 6872645 and 6882051) which broadly cover nanostucture FETs and other devices used in nano-enabled electronics. The technology covered is the use of nanowires, nanorods, or nanoribbons to fabricate FETs and designed to be compatible with traditional thin film manufacture and advanced roll-to-roll coating and printable electronics processes.

Gail Purvis

Figure 1. Selection of peptides with semiconductor binding specificity using phage display. Incubation with phage that displays GaAs-specific peptide, and rhodamine-linked phage-antibody show specific binding to GaAs pattern (Whaley et al. Nature (2000) 405, 665). [Courtesy: http://www.chem.tue.nl/jsmo/MBE/PhageDisplay.htm]
Nanosys also knows the importance of control, and has forgone its forecast initial public offering (IPO) in favour of raising $40m in a private equity financing round. It will use the money raised to fund development and manufacturing scale-up of products. It has development deals with Intel, several government agencies, DuPont, and IN-Q-Tel (the CIA startup). It also has licensing agreements that allow it to try to commercialise intellectual property from the labs of Harvard, MIT, the Hebrew University of Jerusalem and other institutions.

Current product development programs include chemical analysis chips for pharmaceutical drug research, fuel cells for portable electronics, nanostructures for displays and phased array antennas, non-volatile memory for electronic devices, and solid state lighting products.

Dr Lebby also felt that nitride-based material (which he points out ‘in essence is automatically nano, given the material composition and structure in crystal growth”) offered a number of application areas, among them water purification, and the InAs quantum dots (QDs).

Although two disparate meetings and an expert opinion have much in common, the spread of the smallest technology has yet to produced a roadmap. The closest, to date, is the US 2002 International Micro-Nano Roadmap (updated in 2004). MONA is an EU FP6 supported, two-year movement to produce a nanophotonics focused roadmap (expected by mid 2007) to show the most critical scientific, technical, and manufacturing issues of nanophotonics.

Its ten partners are, the French participants: CEA-LETI, Alcatel-Thales III-V lab, EPIC, Opticsvalley and Yole Development; the German players, Aixtron, Schott and VDI-TZ; with the Swedish Acreo, Dutch ASMI, and IMEC-Ghent University, Belgium, completing the group.

The Question of Standards

For MONA delegates, the key questions raised by CEA LETI’s Laurent Fulbert were: how could fabrication of photonic devices converge with complementary metal-oxide–semiconductor (CMOS) fabrication? could specific photonic device fabrication processes reach volume production? can bottom-up and top-down approaches be mixed for nanostructure fabrication? and how to connect the micro to the nano world?

Aixtron’s Rainer Beccard, who presented on equipment for nanophotonics, notes that the compound semiconductor industry has been working with one-dimensional nano materials and structure for 20 years. “Everyone is aware of thin film,” he says. “We think of patterning, and self assembly in two dimensions, which must include lithography and imprint. What is required is a new dimension of control in more than one dimension. History is going to repeat itself, and improving confinement and quantum efficiency will mean thinner and thinner structures.”

World standard authorities are awake to nano needs as shown by the recent publication of the 79-page Porosity and Specific Surface Area Measurement for Solid Materials, interestingly jointly produced by US National Institute of Standards & Technology (NIST) and Germany’s Federal Institute for Materials Research & Testing (BAM). The two research organizations are collaborating to produce certified reference materials and carefully characterised sample benchmarks for evaluating instrument accuracy when used to measure material chemical composition or physical properties. For example NIST and BAM offer samples of alumina beads with certified values for pore volume, mean pore diameter, and most common pore diameter.

This follows close on from NIST’s first standard reference 2841 for the chemical composition of the semiconductor thin film: AlxGa1-xAs epilayers (Al mole fraction, x, near 0.20) to calibrate equipment making the material. AlGaAs is a barrier material to increase conductivity in high speed circuits for wireless communications, lasers for optical disc-drives, bar code scanning, xerography, laser surgery, remote control LEDs and medical instruments. Increased accuracy should reduce wasteful duplication of reference wafers and free exchange of thin film materials between vendors and customers.

To date, NIST has offered an atomic ‘ruler’ for calibrating dimensional measurements of 100 nm and below. NIST has also developed a ‘dramatic’ high-resolution energy-dispersive X-ray detector enabling fast and unambiguous analysis of flaws and contaminants too small to be detected with previous tools used.
in semiconductor manufacturing and is adapting the technology to a transition-edge-sensor X-ray micro-calorimeter - for nanoscale analyses of the chemical composition of a wide range of materials.

NIST-developed measurement techniques allow researchers using the Institute’s cryogenic microwave probe station to determine new material properties in actual devices, rather than as unpatterned thin films. Large arrays of micro calorimeters are developing to track changes in the properties of materials as thin films are deposited on surfaces.

In spintronics, in October, NIST and Colorado University’s JILA demonstrated the scanning photonionisation microscope (SPIM) for analysing the make-up and properties of nanoscale electronics and nanoparticles (Figure 3).

**Equipment**

Beccard’s presentation covered both bottom-up and top-down equipment approaches to nanostructures. Bottom-up includes physical vapour deposition/molecular beam epitaxy (PVD/MBE) for inorganics, III-Vs, and II-VIs; metal-organic chemical vapour deposition (MOCVD) for inorganics, III-Vs, II-VIs, Si, oxides and self assembly; printing for organic and polymer materials; and organic vapour phase deposition (OVPD) for organics and small molecules. Top-down includes optical lithography, E-beam, X-ray and ion-beam lithography, dry-etch, and nano imprint/soft lithography. Metrology includes scanning electron microscopy (SEM), atomic force microscopy (AFM), transmission electron microscopy (TEM), reflectometry, ellipsometry, and the, all vital, in situ metrology for bottom-up techniques.

Looking at the MBE future, Beccard notes that more sophisticated nano devices might require gas or solid source MBE. In MOCVD, self-assembly growth of low dimensional structures is established for GaAs, InP, GaN, ZnO, and related materials with catalyst induced growth of nanostructures. While very precise control of thin layers in one dimension is possible, and customised solutions for nano applications are available, Beccard sees a need to improve reproducibility, with in situ metrology becoming much more important. Other CVD techniques, plasma-enhanced CVD (PECVD), and atomic layer deposition (ALD) standard and modified equipment are in use for SiN, TiN, SiO, SiC, oxides and metal. There is no dedicated equipment available for nanophotonics currently, though the future may hold potential.

In printing, ink jet is used, for full colour displays (polymer organic-LEDs (OLEDs)) non-standard equipment is used, and screen-printing, while not working on the nano scale, is used to deposit nano materials. Here, Beccard feels that dedicated equipment for nano applications is likely, with structuring and modification of deposited layers on the nano scale.

OVPD exists for large area deposition of small molecule OLEDs on large area glasses, and nano resolution is easily achieved in one dimension. The future will need lateral definition of nano structures. Other equipment such as laser ablation, pulsed laser deposition, carbon nanotube (CNT) deposition, sputtering techniques, spin coating, and sol-gel processes all raise issues of reproducibility and scalability, and offer no dedicated nano equipment, as yet.

Optical lithography is well established down to 65 nm/45 nm node (193 nm wavelength immersion technology and holographic lithography allows low cost production of periodic patterns). In the future, extreme ultraviolet lithography (EUV) is required for definition of smaller structures (plasma or synchrotron UV sources) at 13.4 nm wavelengths.

E-beam lithography allows definition of small structure and, while not limited by wavelength, has various other effect restrictions. SEM-type equipment is not suited for volume production and the future will be E-beam projection lithography with a higher throughput. X-ray lithography has very short wavelengths, has tough requirements on masks, needs synchrotron generation, and has no industrial scale use, to date. Ion-beam lithography handles down to 50 nm, while focused ion-beam works on a scanning principle without mask, and ion-projection lithography uses masks.

Reactive-ion and ion-beam etching are established and currently used for nano applications, especially in R&D. Nano applications are not limited by the equipment, but reproducibility of dry etch in combination with masks and materials is critical. For nano imprint and soft lithography available for Si and III-Vs, the structure size is down to 50 nm, but its future requires improvements on accuracy, defects, and reproducibility, and the...
throughput needs to be increased for industrial needs.

‘Current issues for metrology equipment,’ says Bectard, ‘are reliability, standardisation, and calibration, with in situ metrology needing to transfer from R&D to industrial scale, with a choice of suitable in situ methods.’

**Emerging Equipment**

Equipment makers are certainly moving on control metrology and instrumentation. In October, Nanometrics Inc. cross-licensed with ASML to offer customers extendible, open architecture Overlay and CD control solutions that scale beyond 32 nm. Nanometrics has also launched VerteX, a rapid photoluminescence mapping system for compound semiconductors during volume manufacture of optoelectronic devices such as LEDs.

From the UK, AML (newly housed on the Harwell site) has sold a pre-ordered ‘RAD’ system (which activates, aligns, and bonds in situ in one chamber) to QinetiQ; commissioned its first 8-inch ‘RAD’ machines to IME in Singapore and ISSY in the US. The machine allows wafer bonding at the lower temperatures required by the MEMS, IC, III-Vs, and optical industries. Among its cited uses is for high performance LED-bonded reflectors, and advanced bonded substrates such as solar grade (SoG) Si, Si-on-insulator (SOI), Si-on-sapphire (SOS), and GaAs on Si.

The University of Queensland, Australia lab is still developing the use of laser trapping in optical tweezers for measuring the refractive index of 1-5 micrometer sized spherical particles. By not having to suspend particles in special liquids, and with the ability to study polydisperse solutions, the development could be exploited in automated systems, and work is now extending to non-spherical objects.

This year, specialised equipment supplier Molecular Imprints (MI) has supplied its tools to such disparate geographical locations as the University of Cardiff and Twente University. For the LED market, product manager Rob Hershey says MI’s imprint tool development has machines able to process 20 wafers/hr at an incremental cost of less than $20/wafer, empowering chip makers to produce LEDs with photonic crystals or other nano extraction features within the next 12-18 months.

One characteristic of the equipment for nano devices is its ability to adapt to varying materials. BioForce Nanosciences has a Nano eNabler system capable of printing biomolecules onto a wide variety of nano-devices, going into the University of Rochester Medical Centre in New York, to work on technology surrounding smart bandage biomaterial engineering. The benchtop molecular printing system is also working on other substrate materials and many different immobilization chemistries. According to Professor Lewis Rothberg, ‘the system will be a huge boon to our reflective sensing research.’ And although European sales manager Gabor Bethlendy admits ‘we have not yet tried compound semiconductor materials,’ he adds ‘there is no reason to think that it would not work.’

Compound devices are also playing a critical part in test and measurement. In November, SU1 (part of Goodrich Corp.) launched its detection tool, the SU-02-SPC NIR photon counter bench instrument, designed for single photon counting in the near-infrared from 0.9-1.6 µm, based on its high performance InGaAs/InP avalanche photodiodes (APDs). The tool is of use in semiconductor failure analysis, Raman spectroscopy, optical time-domain reflectometry, and quantum key distribution and information processing.

The Tektronix AWG7000 is a 64 M memory for waveform storage and a 0.18 µm BiCMOS SiGe 10-bit digital-to-analog converter (DAC) with a sampling rate to 10 G samples/s. Interleaving two DAC channels, this provides a maximum sampling rate of 20 G samples/s. Rise times of 45 ps are possible in binary signal generation. Modulated RF signals up to 5 GHz (four data points per cycle at 20 G samples/s) can be produced for wideband applications, including radar.

**Nano Markets**

On the topic of nano markets, Dr Lebby cites a ‘Strategies Unlimited’ general timeline for nano technology development, where applications converge around major categories and nano technology becomes commonplace.

At the MONA meeting, Krassimir Krastev of Optics Valley and Yole Development’s addressed the current nano applications and markets. Starting with optical interconnects, where box-to-box is handled by optical fibre, and where the only niche market is aeronautics, the suggestion is that on-chip interconnects of <1 cm is hunting CMOS compatible materials. Si, SiO₂, Si₃N₄ and SiOₓNᵧ could be used as waveguides and cladding (2010-2015).

Nanophotonics should answer to higher performance of signal propagation and ultra large system integration, but the issues of coupling and decoupling light, alignment precision, and temperature resistance exist, as does the need for compatibility with existing equipment and processes, which is highly desirable.

The total available market for all photonics components in the communications industry was put at $10.7bn in 2000, but stood at $2bn in 2003, and $2.5bn in 2004. The limitations and bottlenecks in the next 5-10 years include InP processing, the blur of boundaries between semiconductor materials, the photonic band gap impacting wavelength scale beam manipulation, power maximizing, and the use of quantum devices (QDs) to drive efficiency in industrial lasers.
In displays, it was felt that nanotechnology could bring CNTs to the table, but there is no industrial scale fabrication equipment today for CNTs. But in lighting, new markets are emerging for LEDs and HB-LEDs, and quantum well concepts are under investigation. The challenges are the importance of price for market penetration, the lack of high precision in current equipment for realizing nanostructures, and the European industry tendency to follow rather than innovate.

For data storage, 60% of the market was held by optical media in 2005 and is expected to increase to 77% by 2010. The technical requirement is to overcome the paramagnetic limit of 150 Gbit/in², which could be reached by 2010. The image sensor market is mainly in very small optical products, and limitations range from pixel size, materials for colour filters, on chip image and signal processing, and the wafer integration of optical functions. While nanotechnology could bring a combination of CMOS processes with optimized sensitive thin layer above IC detection, so far, there is no compatibility with current manufacturing processes.

As for photovoltaics (PVs), the challenges are stability, lifetime, large area processing, efficiency, reducing silicon wafer thickness, and improving factory yield and throughput. Organic PVs with nanostructured surfaces could overcome some of these limitations.

At the SEMI nano event, PV markets for equipment may be moving away from vacuum deposition. Both Konarka Technologies and Nanosolar are counting on new nanomaterial technologies to print their low-temperature solar films, whether with cold sintered nano crystals of TiO₂ (Figure 4) coated with light-absorbing dye, or quantum dots, nano templates or nanoparticle ink for copper indium gallium diselenide (CIGS) thin films. The low-temperature technologies could mean much of the thin-film photovoltaic market will use printing equipment, not conventional vacuum deposition tools, and market researcher, NanoMarkets, projects printed thin-film photovoltaics will ramp up to surpass vacuum deposition in dollar value by 2012.

It is also worth noting that Kornaka is working with the Ecole Polytechnique Federale of Lausanne University, to enable power generation capabilities to be woven in rather than merely applied. The stated goal is a fabric sample with at least 4% efficiency rating. Meantime Sharp Solar is to ship GaAs substrates this year, with at least 4% efficiency rating.

Materials

One of the most vibrant current development markets at present is that of the material behavioural skills at the nano scale, and considerable research work is being undertaken to uncover new nano characteristics and develop processes that can exploit these.

One big eye opener to emerge from Penn State and the UK’s University of Southampton is the year’s development of optical fibres. The breakthrough by Penn State and the UK’s University of Southampton is the year’s development of optical fibres. The breakthrough by Penn State associate professor of chemistry, John Badding, and senior research fellow at the Optoelectronics Research Centre at Southampton, move the optical electrical optical problem into an all-optical solution. It involves a process to embed semiconductor materials inside optical fibre (Figure 5), essentially inserting the switching and modulating hardware inside the fishing-line-thick flexible glass tubes. Using CVD to deposit germanium and other semiconductor material inside the fibre at 1,000 times atmospheric pressure and at temperatures of up to 500°C they have created a uniform coating the whole length of the fibre. This allows you to organize materials at a nanoscale dimension in ways you couldn’t organize them before... the essence of making advanced electronic and photonic devices,” says Badding.

Technologies & Devices International Inc. (TDI) has had major results in GaN compound semiconductor material technology by fabricating GaN quantum well (QW) structures using hydride vapour phase epitaxy (HVPE). (The GaN-based market is projected to reach US$5bn in 2007 and exceed US$7bn by 2009.)

Prof Subhash Mahajan, student Fanyu Meng and post-doctoral fellow Ranjan Datta, at Arizona State University, made material characterisations of GaN single and multiple quantum well structures fabricated at TDI (Figure 6). “HVPE is a well known method to fabricate thick...
GaN layers. We never expected this technology to produce nanometre thick GaN layers and multi-layer structures. However, our TEM measurements performed on recent TDI’s samples proved that it is achieved,” they note.

Graphene (Figure 7) and the carbon nanotube developments, for example, seem to appear weekly. Lawrence Berkeley National Laboratory scientists recently announced a bi-layer graphene as a switching device in nanoscale electronics. Northwestern University researchers have demonstrated a carbon nanotube-based NEMS switch exhibiting bistability based on current tunneling. Physicists at UCB show graphene structures can conduct electron spin in one orientation, but not the other. Ray Baughman at University of Texas has led group development in an efficient new way to make thin sheets of nanotubes that might be rapidly adaptable to commercial production, by attaching an adhesive strip to the edge of a ‘bundle’ of nanotubes, and pulling the strip away at a steady speed, drawing out the vertical tubes to lie in horizontal rows. Sheets 20 microns thick, 5 cms wide and a metre long can be made in less than a minute. Wetting and evaporation give the sheets 50 nm density. Attributes are strength, lightness, transparency, flexibility, and electrical conductivity, pointing to their use as electrodes in solar cells, organic LED displays, and even artificial muscles.

In another approach, researchers at Stanford University create functional transistors using an etching process that can be integrated with standard silicon chip processes, and overcomes the difficulty of separating semiconducting tubes from a typical batch, in which about a third of the material is metallic. The Stanford group grows a mixed bunch of semiconducting and metallic nanotubes on a silicon wafer and has them bridge the source and drain of a transistor. They then expose the devices to methane plasma at 400°C to eat away the carbon atoms, but only in the metallic nanotubes, converting them into a hydrocarbon gas. (Plasma also etches out nanotubes with diameters smaller than about 1.4 nm.) The wafer is subsequently treated in a vacuum at 600°C to get rid of carbon-hydrogen groups, leaving behind purely semiconducting nanotubes with a consistent range of diameters.

At the UCB and the Lawrence Berkeley National Laboratory, researchers also have a method for controllably altering the diameter of individual CNTs and can shrink individual nanotubes to any desired diameter. The process can be repeated in a highly controlled fashion, yielding a high-quality CNT of any preselected and precise diameter. The method involves high-temperature that shrinks regular-sized CNTs and reforms them into high-quality tubes of a smaller diameter.

Rensselaer Nanotechnology Centre has developed two new techniques to place carbon nanotube patterns on metals surfaces. One is a floating catalyst CVD for depositing CNTs directly on metals. The other is a contact printing method for CNT arrays on conducting substrates.

Even the traditional compound materials are turning new tricks at the nanoscale. Livermore postdoctoral fellow, physicist Christoph Bostedt, has used synchrotron radiation at Lawrence Berkeley National Laboratory’s Advanced Light Source (ALS) for photoemission spectroscopy and X-ray absorption studies of the electronic microstructure of germanium nanocrystal films, has shown that quantum confinement effects are greater in germanium nanocrystals than in silicon nanocrystals (Figure 8) and in silicon nanocrystals, for particles smaller than 2 nm. Strong confinement and fast opening of the optical gap gives a highly ‘tunable’ material, meaning Ge nanocrystals would be especially useful in extreme sensitivity detectors and optoelectronic applications. The laboratory workers also showed that Ge nanocrystals embedded in silica glass don’t melt until nearly 200ºK above the melting point of bulk germanium and have to be cooled more than 200ºK before they resolidify.

Nanodiamond work at Livermore shows a nanodiamond must be reduced to less than 2 nm before its optical gap increases beyond that of the bulk form, differing from Si and Ge where quantum-confinement effects persist in particles of up to 6-7 nms. At the University

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**Table 1. General Timeline of Nanotechnology Development.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
<th>Products with wider applicability begin to emerge, beginning with new nanotech materials. Government R&amp;D and venture financing grows as other applications came into view. Heavy overinvestment leads to a view that the subject is over-hyped, even with strong commercialization progress.</th>
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<tr>
<td>Late 1990s to 2010</td>
<td>Government initiatives and early commercialisation</td>
<td>Some giant applications, such as displays, LEDs, electronics, drug delivery, fuel cells, and solar cells, gain market traction. Applications converge around a few main categories. Users and suppliers begin to take nanotechnology elements for granted and nanotechnology becomes commonplace.</td>
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<tr>
<td>2010 and Beyond</td>
<td>Convergence and assimilation</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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Source: Strategic Analysis
of California, Riverside, theoretical work suggests that the electron mobility in silicon nanowires embedded in diamond can be made a factor of two higher at room temperature. Microcrystalline diamond or diamond-like carbon could help offset cost, is CMOS compatible, and seen as a way around SiGe thermal problems.

Virginia-based Luna nanoworks is now nearing commercialization of its Trimetasphere buckyball carbon molecules (Figure 9), where fullerene spheres enclose three metal atoms in a nitride molecule. The nanomaterial offers novel electronic, optical and magnetic properties. Discovered in the laboratory of Drs. Harry Dorn and Steve Stevenson at Virginia Tech, the metal atoms can be any of the series Scandium, Yttrium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, or Erbium, or can be a mixed complex.

The entrapped metals provide unique physical, chemical, thermal, magnetic, optical, and electronic properties that differentiate them from other carbon nanomaterials. Among the anticipated uses...

One Man’s SiGe Nano Work

Durga Misra, PhD, a professor in the electrical and computer engineering department at New Jersey Institute of Technology, was named a Fellow of the Electrochemical Society, becoming one of 14 fellows newly selected in 2006 for their individual contributions and leadership in the achievement of science and technology in the area of solid-state sciences and electrochemistry. Misra’s research focuses on semiconductor devices and integrated circuits for nanoelectronics. He has developed materials and processes to enhance the performance and reliability of nanoscale semiconductor devices and his research aims to decrease the cost and size of devices. Applications for high-performance and low-power semiconductor devices include more powerful and efficient wireless communication tools and computing systems for the commercial market, national defence, and homeland security.

Si\textsubscript{0.4}Ge\textsubscript{0.6} Photodiode as Infrared Photodetector

1. Design

The objective of this work is to design a photodiode with SiGe layers and optimize it for maximum (optical) quantum efficiency for the given wavelength (1300 nm). Figure 1. Cross section of the SiGe photodiode.
for Trimetaspheres is their use as a contrast agent in MRI, and for new types of highly efficient solar cells.

If the new material prospects are a bit rich for the blood, there’s plenty going on in the mundane world of substrates. In the US, Nitronex Corp has a technique for growing very high-purity gallium nitride on silicon that is based on a Pendeoepitaxy crystal growth process. This reduces the number of defects found in GaN crystals. Used in conjunction with a new platform technology aimed at growing GaN on 4- and 6-inch silicon wafers, the company is now building and sampling discrete power amplifiers and transistors for wireless base-stations.

In Europe, the results of the Hyphen project show that Picogiga International has excellent initial material characterisation results for GaN on compound engineered substrates. Picogiga has been working with seven project partners: the University of Padova, Alcatel-Thales III-V lab, Hungary’s Research Institute for Technical Physics and Materials Science, Norstel Sweden (which grows HTCVD high purity SiC wafers), Poland’s Institute of Electron Technology, and the IEMN research unit of CNRS, as well as United Monolithic Semiconductors (Thales-Eades JV). The aim is to bridge the gap between low performance, low cost, single crystal silicon, and high performance, high cost, single crystal SiC used as the substrates for GaN-based RF devices.

In the first year, the project compared GaN on bulk Si and GaN on bulk SiC, with GaN grown on silicon on poly-crystalline silicon carbide (SopSiC) and SiC on poly-crystalline SiC (SiCopSiC) engineered using Soitec’s Smart Cut technology. All the critical performance factors of GaN on composite substrates are equal to, or even better than, current industry standard materials. Substrate comparisons were assessed using MOCVD and MBE. The new composite substrates demonstrate superior results in pilot production yield and repeatability. Epitaxy GaN HEMT on SopSiC composite is more reliable than conventional Si substrates and better suited to high volume than bulk SiC substrates for a frequency scale less than 10 GHz.

Compound nano’s present and accelerating future rests not only on material control but also on a multi-dimensional view of problems and their solutions.

The band gap profile for the previous diode (Figure 2) is given below (Figure 3).

The band gap profile of the modeled photodiode (Figure 4) is given below (Figure 5).

The dark current characteristics were then calculated for the above structure for device application. Many companies are fabricating this device by MBE or CVD.

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